Focus on CSIR Research in Pollution and Waste

CSIR Natural Resources and the Environment
2007

Cellulose degradation, volatile fatty acid formation and biological sulphate removal operating an anaerobic hybrid reactor

Background

The biological sulphate removal technology requires carbon and energy sources to reduce sulphate to sulphide. Plant biomass, e.g. cut grass, is a sustainable source of energy when cellulose is utilised in the anaerobic degradation to produce Volatile Fatty Acids. This process involves cellulose utilizing micro-organisms, present in the guts of ruminants (Figure 1). The Sulphate Reducing Bacteria (SRB) can also assist in the degradation of complex polymers and can utilize H_2, and VFA as energy sources. A close syntrophy exists between the VFA and H_2 producing and utilising micro-organisms, which is beneficial for sulphate removal, using a single stage anaerobic hybrid reactor.

Aim of study

The aim of this study was to investigate the sulphate removal rate operating an anaerobic hybrid reactor using the fermentation products of cellulose in grass cuttings, as electron donors, treating synthetic SO_4 rich water as well as pre-treated mine effluent.

Materials and methods

Feed Water

Initially synthetic sulphate-rich water (5 ℓ/d) and later pre-treated acid mine water (15 and 30 ℓ/d) were used as feed water for the hybrid reactor system (FR). The synthetic feed water contained a SO_4 concentration of ≈ 2500 mg/ℓ, (Na_2SO_4), as well as macro- and micronutrients. Due to the acidic and metal character of the mine water, it was pre-treated with the alkalinity and sulphide rich effluent of the biological reactor in a 1:1 ratio, to increase the pH and to precipitate the metals as metalsulphides. The feed water entered FR at the top to get into contact with the grass cuttings. A recycle stream (360 ℓ/d) was installed from the fermentation part of the reactor to the top of the reactor for mixing purposes. The effluent left FR at the bottom. (Figure 2).

Reactor System and Biomass

A 20 ℓ perspex one stage anaerobic hybrid reactor system operating at 37-39 °C, consisting of a fermentation (FR) and a sulphate removal section (SR) was used,. The bottom part contained ceramic rings as packing material. A 250 mℓ mixture of SRB biomass (VSS of 10 g/ℓ) formed a SRB biofilm on the ceramic rings. The top part of the reactor contained grass cuttings, to which rumen fluid (250 mℓ, VSS of 11 g/ℓ) was added. The pH of the reactor was 6.6-6.9

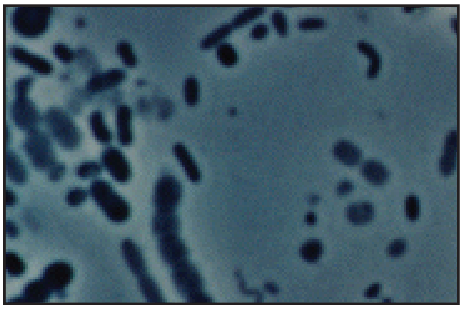
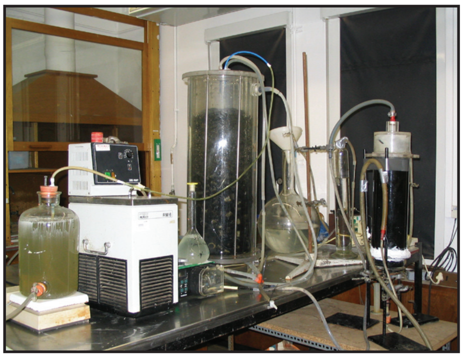


Fig 1. The rumen fluid of ruminants contaibn many micro-organisms that can degrade cellulose to VFA and H_2



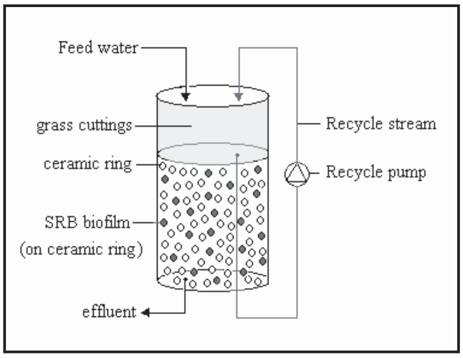


Fig 2. Schematic overview of the hybrid reactor system and the laboratory scale hybrid reactor system.

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Carbon and Energy source

The fermentation products of cellulose served as the carbon and energy source in the reactor.

Experimental

During the first part of the study, fresh grass (150 g) was added to FR on days 1, 32, 46 and 62, resulting in 4 experimental periods, while there were three periods feeding the diluted mine water, based on feed rates and grass addition: d1-37, d41-49 and d50-78

Results

Sulphate removal when feeding synthetic feed water

The graphs in Figure 3 show the relationship between the COD concentration and the sulphate reduction in FR. During the periods that the COD concentration was lower than 1000 mg/ℓ, the sulphate reduction is less efficient (≈ day 50). Figure 3 shows that after each grass addition (150 g on days 1, 32, 46 and 62), the COD concentration increased, while it decreased during the periods of sulphate reduction. The SO_4 removal was 84, 91, 88 and 80% and 2.04, 2.52, 2.33 and 2.29 g/ℓ, respectively, during the 4 periods.

VFA utilisation when feeding synthetic feed water

Oxidation of propionate and butyrate occur during the biological sulphate removal process to produce acetate: [1] and [2].

$$\text{Propionate}^- + \tfrac{3}{4}\,SO_4^{2-} \longrightarrow \text{Acetate}^- + HCO_3^- + \tfrac{3}{4}\,HS^- + \tfrac{1}{4}\,H^+ \quad [1]$$

$$\text{Butyrate}^- + \tfrac{1}{2}\,SO_4^{2-} \longrightarrow 2\ \text{Acetate}^- + \tfrac{1}{2}\,HS^- + \tfrac{1}{2}\,H^+ \quad [2]$$

No propionate and butyrate were measured during the experimental periods, while the acetate concentration decreased from 649 to 449, to 88 and to 27 mg/ℓ, respectively. Due to the low concentrations of butyric and propionic acids, it was hypothesized that the acetic acid was possibly utilised for sulphate reduction.

Sulphate removal when feeding pre-treated AMD

The SO_4 concentration in the treated water is unstable, however, after day 75, it was <500 mg/ℓ for several consecutive days (Figure 4). On day 50, the feed rate was increased to 30 ℓ/d, which resulted in an average sulphate load of 70.5 g/d. During this period, different amounts of grass were added. When a higher amount of grass was added, better SO_4 removal was observed The highest sulphate reduction was obtained during period 2, when the feed rate was 15 ℓ/d and 20 g/d grass was added during 8 days (160 g grass) removing 205 g SO_4. These results indicated that 1 g grass removed 1.34 g SO_4. Sustained sulphate reduction can be maintained when grass is continuously added to the reactor. No VFA were measured in FR, indicating that all produced VFA were utilised for SO_4 removal.

Conclusions

- The fermentation products of grass cuttings can serve as the carbon and energy source for continuous biological sulphate removal. The produced VFA, mainly propionate and butyrate, were used as carbon and energy sources.
- When feeding synthetic SO_4 rich water at 5 ℓ/d and adding 150 g grass per two weeks, sustained sulphate removal during four experimental periods (84, 91, 88 and 80%, respectively) was observed.
- When feeding pre-treated mine water at 15 ℓ/d, the highest sulphate removal was 205 g, adding 180 g grass over a period of 8 days.
- When the feed rate was increased and when the grass allocation remained constant, a lower SO_4 removal was observed, indicating the direct relationship between the quantity of grass added and the sulphate removal rate.

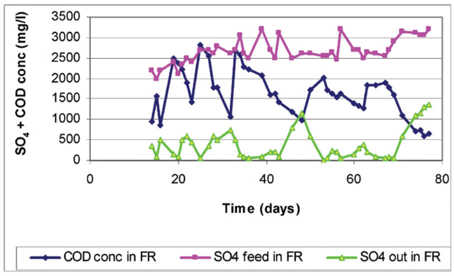

Figure 3. SO_4 concentration in feed and treated water + COD concentration in FR, feeding synthetic feed water

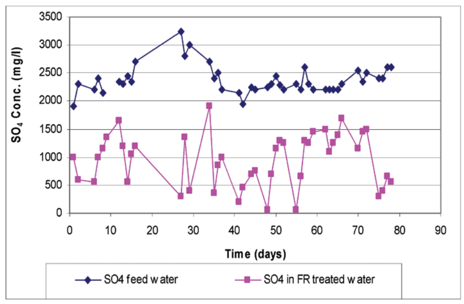

Figure 4. SO_4 concentration in feed and treated water, feeding pre-treated AMD

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